

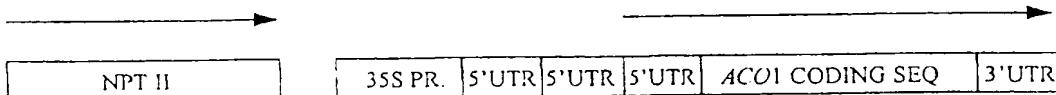
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(54) Title: GENE SILENCING



(57) Abstract

Constructs and methods for enhancing the inhibition of a target gene within an organism involve inserting into the gene silencing vector an inverted repeat sequence of all or part of a polynucleotide region within the vector. The inverted repeat sequence may be a synthetic polynucleotide sequence or comprise a modified natural polynucleotide sequence.

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GENE SILENCING

This invention relates to the control of gene expression, more particularly to the inhibition of expression, commonly referred to as "gene silencing".

5

Two principal methods for the modulation of gene expression are known. These are referred to in the art as "antisense downregulation" and "sense downregulation"(also, referred to as "cosuppression"). Both of these methods lead to an inhibition of expression of the target gene.

10

In antisense downregulation, a DNA which is complementary to all or part of an endogenous target gene is inserted into the genome in reverse orientation. While the mechanism has not been fully elucidated, one theory is that transcription of such an antisense gene produces mRNA which is complementary in sequence to the mRNA product transcribed from the endogenous gene: that antisense mRNA then binds with the naturally produced "sense" mRNA to form a duplex which inhibits translation of the natural mRNA to protein. It is not necessary that the inserted antisense gene be equal in length to the endogenous gene sequence: a fragment is sufficient. The size of the fragment does not appear to be particularly important. Fragments as small as 42 or so nucleotides have been reported to be effective. Generally somewhere in the region of 50 nucleotides is accepted as sufficient to obtain the inhibitory effect. However, it has to be said that fewer nucleotides may very well work: a greater number, up to the equivalent of full length, will certainly work. It is usual simply to use a fragment length for which there is a convenient restriction enzyme cleavage site somewhere downstream of fifty nucleotides. The fact that only a fragment of the gene is required means that not all of the gene need be sequenced. It also means that commonly a cDNA will suffice, obviating the need to isolate the full genomic sequence.

15

The antisense fragment does not have to be precisely the same as the endogenous complementary strand of the target gene. There simply has to be sufficient sequence similarity to achieve inhibition of the target gene. This is an important feature of antisense technology as it permits the use of a sequence which has been derived from one plant species to be effective in another and obviates the need to construct antisense vectors for each

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individual species of interest. Although sequences isolated from one species may be effective in another, it is not infrequent to find exceptions where the degree of sequence similarity between one species and the other is insufficient for the effect to be obtained. In such cases, it may be necessary to isolate the species-specific homologue.

5 Antisense downregulation technology is well-established in the art. It is the subject of several textbooks and many hundreds of journal publications. The principal patent reference is European Patent No. 240,208 in the name of Calgene Inc. There is no reason to doubt the operability of antisense technology. It is well-established, used routinely in laboratories around the world and products in which it is used are on the market.

10 Both overexpression and downregulation are achieved by "sense" technology. If a full length copy of the target gene is inserted into the genome then a range of phenotypes is obtained, some overexpressing the target gene, some underexpressing. A population of plants produced by this method may then be screened and individual phenotypes isolated. A similarity with antisense is that the inserted sequence need not be a full length copy. The
15 principal patent reference on cosuppression is European Patent 465,572 in the name of DNA Plant Technology Inc. There is no reason to doubt the operability of sense/cosuppression technology. It is well-established, used routinely in laboratories around the world and products in which it is used are on the market.

Sense and antisense gene regulation is reviewed by Bird and Ray in Biotechnology
20 and Genetic Engineering Reviews 9: 207-227 (1991). The use of these techniques to control selected genes in tomato has been described by Gray et.al., Plant Molecular Biology, 19: 69-87 (1992).

Gene silencing can therefore be achieved by inserting into the genome of a target organism an extra copy of the target gene coding sequence which may comprise either the
25 whole or part or be a truncated sequence and may be in sense or antisense orientation. Additionally, intron sequences which are obtainable from the genomic gene sequence may be used in the construction of suppression vectors. There have also been reports of gene silencing being achieved within organisms of both the transgene and the endogenous gene where the only sequence identity is within the promoter regions.

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Gene control by any of the methods described requires insertion of the sense or antisense sequence, under control of appropriate promoters and termination sequences containing polyadenylation signals, into the genome of the target plant species by transformation, followed by regeneration of the transformants into whole plants. It is probably fair to say
5 that transformation methods exist for most plant species or can be obtained by adaptation of available methods.

The most widely used method is *Agrobacterium*- mediated transformation, mainly for dicotyledonous species. This is the best known, most widely studied and, therefore, best understood of all transformation methods. The rhizobacterium *Agrobacterium tumefaciens*,
10 or the related *Agrobacterium rhizogenes*, contain certain plasmids which, in nature, cause the formation of disease symptoms, crown gall or hairy root tumours, in plants which are infected by the bacterium. Part of the mechanism employed by *Agrobacterium* in pathogenesis is that a section of plasmid DNA which is bounded by right and left border regions is transferred stably into the genome of the infected plant. Therefore, if foreign DNA
15 is inserted into the so-called "transfer" region (T-region) in substitution for the genes normally present therein, that foreign gene will be transferred into the plant genome. There are many hundreds of references in the journal literature, in textbooks and in patents and the methodology is well-established.

Various methods for the direct insertion of DNA into the nucleus of monocot cells
20 are known.

In the ballistic method, microparticles of dense material, usually gold or tungsten, are fired at high velocity at the target cells where they penetrate the cells, opening an aperture in the cell wall through which DNA may enter. The DNA may be coated on to the microparticles or may be added to the culture medium.

25 In microinjection, the DNA is inserted by injection into individual cells via an ultrafine hollow needle.

Another method, applicable to both monocots and dicots, involves creating a suspension of the target cells in a liquid, adding microscopic needle-like material, such as silicon carbide or silicon nitride "whiskers", and agitating so that the cells and whiskers
30 collide and DNA present in the liquid enters the cell.

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In summary, then, the requirements for gene silencing using both sense and antisense technology are known and the methods by which the required sequences may be introduced are known.

The present invention aims to, *inter alia*, provide a method of enhancing the control
5 of gene expression.

According to the present invention there is provided a vector for enhancing the inhibition of a selected target gene within an organism, comprising a gene silencing vector characterised in that the said gene silencing vector includes a inverted repeat of all or part of a polynucleotide region within the vector.

10 The inverted repeat sequence may be a synthetic polynucleotide sequence and its inverted repeat sequence or an inverted repeat of all or part of the said gene silencing vector or an inverted repeat of the 5'-untranslated region of the gene silencing vector.

The inverted repeat may be separated from the polynucleotide region by a sequence of nucleotides.

15 The invention also provides a method of controlling the expression of a DNA sequence in a target organism, comprising inserting into the genome of said organism an enhanced gene silencing vector as defined above.

20 In a preferred embodiment a vector for enhanced gene silencing comprising in sequence a promoter region, a 5'-untranslated region, a transcribable DNA sequence and a 3'-untranslated region containing a polyadenylation signal, characterised in that the said construct includes an inverted repeat of a region of said vector.

It is preferred that the inverted repeat is a fragment of the 5'-untranslated region of the said vector. The vector may have two tandem copies of the inverted repeat.

25 In simple terms, we have found that the inhibitory effect of a gene-silencing vector can be enhanced by creating in the vector an inverted repeat of a part of the sequence of the vector. Alternatively the inverted repeat may be of a synthetic sequence which may be created independently of the vector itself and then inserted into the vector sequence. While the mechanism by which the enhancement is achieved is not fully understood we understand that the minimum required for such a vector is a region or regions which identify the gene
30 targeted for silencing and an inverted repeat of a part of that region or, as explained above an inserted sequence and its inverted repeat. The region of the vector which identifies the gene

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targeted for silencing may be any part of that endogenous gene which characterises it, for example, its promoter, its 5'-untranslated region, its coding sequence or its 3'untranslated region. We have also found that the vector used in this invention will silence the expression of the target gene and also any members of the gene family to which the targeted gene belongs.

Although the mechanism by which the invention operates is not fully understood, we believe that creation of an inverted repeat promotes the formation of a duplex DNA between the selected sequence and its inverted.

The inverted repeat may be positioned anywhere within the vector such as within the 10 promoter region, the 5' untranslated region, the coding sequence or the 3' untranslated region. If the inverted repeat is based on a contiguous sequence within the promoter region, then it is preferred that the inverted repeat is located within the promoter region. If the inverted repeat is based on a contiguous sequence within the 5' untranslated region, then it is preferred that the inverted repeat is located within the 5' untranslated region. If the inverted 15 repeat is based on a contiguous sequence within the coding region, then it is preferred that the inverted repeat is located within the coding region. If the inverted repeat is based on a contiguous sequence within the 3' untranslated region, then it is preferred that the inverted repeat is located within the 3' untranslated region.

The selected polynucleotide sequence and its inverted repeat may or may not be 20 separated by a polynucleotide sequence which remains unpaired when the 5' untranslated region and the inverted repeat have formed a DNA duplex. It is preferred however, that the chosen contiguous sequence and its inverted repeat are separated by a polynucleotide sequence which remains unpaired when the 5' untranslated region and the inverted repeat have formed a DNA duplex.

It is further preferred that the inverted repeat is based on the 5' untranslated sequence. It is also preferred that the inverted repeat is positioned upstream of the coding sequence. It is further preferred that the inverted repeat is positioned between the 5' untranslated region and the coding sequence. It is further preferred that the 5' untranslated region and the inverted repeat are separated by a polynucleotide sequence which remains unpaired when the 25 5' untranslated region and the inverted repeat have formed a DNA duplex.

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Suppression can also be achieved by creating a vector containing an inverted repeat sequence which is capable of forming a duplex DNA within the promoter region of the target gene. This obviates the need to include any specific coding sequence information about the gene to be suppressed since the vector would allow suppression of the promoter within the organism and hence the expression of the target gene. Alternatively vectors may be created which are lacking a promoter sequence but which contain an inverted repeat of a sequence within the 5' untranslated region, the coding region or the 3' untranslated region.

The 5' or 3' untranslated regions of a gene suppression vector can also be replaced with a synthetic 5' or 3' untranslated regions which comprises a polynucleotide part and inverted repeat separated by a polynucleotide sequence which remains unpaired when the said polynucleotide part and the inverted repeat form a DNA duplex. It is preferred to construct a synthetic 5' untranslated region. It is further preferred to construct the synthetic 5' untranslated region comprising sequentially, a 33 base polynucleotide part and a 33 base polynucleotide inverted repeat separated by a 12 base polynucleotide.

Where it is desired to use an inverted repeat sequence within the 5' untranslated region, the coding sequence or the 3' untranslated region, gene silencing vectors constructed with inverted repeats within any one of these regions may additionally enable the silencing of genes that are homologous to the coding sequence present in the silencing vector. Therefore when it is desired to silence genes homologues within an organism the construction of a silencing vector containing an inverted repeat within the 5' untranslated region, the coding sequence or the 3' untranslated region may allow the silencing of all the genes exhibiting sequence homology to the coding sequence within the construct. Homology/homologous usually denotes those sequences which are of some common ancestral structure and exhibit a high degree of sequence similarity of the active regions. Examples of homologous genes include the ACC-oxidase enzyme gene family which includes ACO1 and ACO2.

Any of the sequences of the present invention may be produced and manipulated using standard molecular biology techniques. The sequences may be obtained from a desired organism source such as plant sources and modified as required or synthesised *ab initio* using standard oligosynthetic techniques.

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Without wishing to be bound by any particular theory of how it may work, the following is a discussion of our invention. 96% of tomato plants transformed with an ACC-oxidase sense gene containing two additional, upstream inverted copies of its 5' untranslated region, exhibited substantially reduced ACC-oxidase activity compared to wild type plants. Only 15% of plants transformed with a similar construct, without the inverted repeat, had reduced ACC-oxidase activity. Both populations had similar average numbers of transgenes per plant. Treatment of tomato leaves with cycloheximide caused a strong, reproducible increase in the abundance of ACC-oxidase transcripts and was used in the study of suppression by ACC-oxidase sense transgenes in preference to wound induction used in previous studies. The relative abundance of unprocessed and processed ACC-oxidase transcripts in suppressed and non-suppressed plants was assayed by ribonuclease protection assays, providing an indirect measure of transcription and mRNA accumulation which did not rely upon assaying isolated nuclei. This analysis indicated that the suppression of ACO1 gene expression was mainly post-transcriptional. Using the same type of RPA assay similar results were obtained from plants containing suppressing polygalactonase-sense or ACO-antisense transgenes.

There are now numerous examples of the inactivation of homologous sequences in plants. The term "homology dependent gene silencing" (HDGS) best describes all of these although it should be noted that in most examples the "silencing" is not complete and a low level of gene expression remains. Throughout this specification we will use the classification most-recently outlined by Matzke and Matzke, Plant Physiol. 107: 679-685 (1995) in which different examples of HDGS were divided into three main groups; cis-inactivation, trans-inactivation, and sense-suppression. Down regulation by antisense genes bears many similarities to the last of these and has been suggested to operate by the same mechanism (Grierson et al, Trends Biotechnol. 9: 122-123 (1991)). Both sense and antisense transgenes have been widely used to reduce the expression of homologous endogenous genes in plants. Although the underlying mechanisms of HDGS remain obscure, this technology has found numerous applications not only in fundamental research but also in commercial biotechnology ventures and new food products are already on the market.

At present, obtaining a large number of strongly suppressed, transgenic lines is more a matter of luck than judgement. A positive correlation between the presence of repeated

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transgene sequences and the incidence of HDGS has been noted. However single locus-transgene insertions associated with HDGS have also been reported.

There is an emerging consensus that different examples of HDGS can be classified on the basis of whether or not the transcription of the target gene is affected. Examples of transcriptional suppression have been described. Where the homology between interacting genes resides within transcribed sequences, HDGS has been shown to be a post-transcriptional effect. Despite this apparently precise demarcation, several similarities exist between some examples in the two different categories. These include variegated patterns of silencing, increased methylation of genes participating in silencing and the frequent observation that silencing loci contain repeated sequences.

Although transcriptional silencing must occur in the nucleus, post-transcriptional silencing might occur in either or both the nucleus or cytoplasm. There is evidence that the abundance of processed, nuclear RNA of silenced genes was unaffected and suggested an effect upon transport into or degradation within the cytoplasm. More compelling evidence that post-transcriptional HDGS occurs outside the nucleus is the relationship between gene silencing involving nuclear transgenes and resistance to cytoplasmically replicating RNA viruses. Transgenic plants containing transgenes that suppress the activity of other transgenes (e.g. GUS) or endogenous genes (e.g. PG) are also resistant to RNA viruses which have been engineered to include sequences from those genes. Nevertheless, nuclear features such as transgene methylation and complexity of transgene loci were found positively to correlate with virus resistance. In almost all instances of HDGS, the source of the silencing is nuclear (even if the manifestation is cytoplasmic). However, silencing of a nuclear gene by a cytoplasmic element has been demonstrated by the suppression of phytoene desaturase in plants infected by a recombinant virus containing sequences from that gene.

Although, there are now numerous examples of post-transcriptional suppression of plant genes by HDGS, as yet, there is no information as to whether the increased turnover of pre-mRNA is related to or distinct from other cellular, RNA turnover processes. Degradation of RNA in plants is poorly understood but there is evidence that translation is involved. For example, the very short half lives (around 10 minutes) of small auxin up RNAs (SAURS) can be markedly prolonged by treatment with cycloheximide.

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This invention gives a striking increase in the frequency of HDGS following the inclusion of a short repeated region within a transgene. Expression of the target gene encoding the terminal ethylene biosynthetic enzyme ACC-oxidase, in tomato was suppressed by such constructs mainly post-transcriptionally. This was shown to be true for other examples of sense and antisense suppression in tomato. Cycloheximide was found to be a potent and reliable inducer of ACO gene expression but did not ameliorate the silencing.

The invention will now be described, by way of illustration, in the following Examples and with reference to the accompanying Figures of which:

10 **Figure 1.** (A) ACO1 gene silencing vector.

(B) ACO1 gene silencing vector containing tandem inverted repeats of the 5' untranslated region.

15 **Figure 2.** Illustrates the relative ACC-oxidase activity in both types of transgenic plant and V = transgenic plants containing construct V (Figure 1B).

Figure 3. Tomato plant ACC Oxidase activity of transgenic transformants containing pHIR-ACO (as illustrated in SEQ ID No 10). The graph also includes C12ACO (overexpression control) an untransformed wild type and TOM13 strong antisense gene silenced control.

20 **Example 1.0**

Construct V (Figure 1) was made in the following manner: 79 base pairs of the 5' untranslated region of the tomato ACO1 cDNA was amplified by PCR and two copies were ligated in tandem in the reverse orientation immediately upstream of the ACO1 cDNA which contains its own polyadenylation signal in its 3' untranslated region (construct C). Both 25 were ligated downstream of the CaMV 35S promoter and then transferred to the binary vector, Bin19. Figure 1 shows the basic details of constructs "C" and "V". These were used to transform tomato plants (Ailsa Craig) by *Agrobacterium* mediated DNA transfer. 13 and

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28 individual kanamycin resistant calli were obtained with constructs "C" and "V" respectively and these were regenerated into plants.

The nucleotide sequence of the promoter and 5' untranslated region of the ACO1 gene is given as SEQ ID NO 1 hereinafter. The 79bp referred to above begins at base 5 number 1874 and stops at the base immediately preceding the translation start codon (ATG) at number 1952.

Example 1.1

To screen the population for any effects on ACO gene expression, relative ACO activity was measured from untransformed and transformed plants. The production of 10 ethylene from leaf discs supplemented with the ethylene precursor, 1-aminocyclopropane-1-carboxylic acid, was measured at least three times from each plant. The cutting of the discs by a cork borer wounds the leaves and stimulates the expression of the ACO1 gene. ACC-oxidase activity in both types of transgenic plant relative to wild type values are shown in 15 Figure 2. There was a dramatic difference in ACO activity between the two populations, with plants containing the inverted repeat (V line) showing very strong suppression. The majority (11 out of 13) of plants of the C line did not show suppression of ACO activity but overexpression, compared to wild-type plants, as would be expected since this construct contained a translatable ACO1 coding sequence.

To test for the presence of the transgenic ACO sequence, DNA from the plants was 20 analysed by PCR using two oligos homologous to and complementary with the beginning and end respectively of the ACO1 coding sequence. This combination co-amplifies 1500 bp of the endogenous ACO1 gene (which acts as an internal positive control) and the ACO1 sense transgene as a 1000 bp fragment (since it was derived from a cDNA and so has no introns). The amplified region does not include the repeated region of the V-type transgene. 25 The two fragments were separated by gel electrophoresis and detected by staining with ethidium bromide. This showed the presence of the transgene in all plants of the C line and all plants of the V line except one (V2) which also had no reduced ACC-oxidase activity (Figure 2).

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Example 1.2

It was considered possible that the repeated region in the transgene might have affected the number of transgenes which integrated into the genome and that this was the actual source of high frequency silencing. The PCR assay described above can be used to estimate the transgene copy number if the following assumptions are made:

- 1) that in any transgenic plants there was no variation in the number of endogenous ACO1 genes per genome;
 - 2) that the amplification efficiency ratio (endogenous ACO1 DNA: transgenic ACO1 DNA) is constant;
 - 10 3) the reaction is sampled at low DNA concentration to minimise product re-annealing.
- Since we were only concerned with estimating the number of transgenes in the two lines relative to each other and not absolute quantification of transgene copy number, we did not employ synthetic combinations of "transgene" and "endogenous gene" DNA as standards.

15 After 20 cycles of amplification, gel-electrophoresis, Southern blotting, and hybridisation with a radioactively labelled ACO1 cDNA, the signal from endogenous and transgenic ACO1 DNA was visualised and quantified by phosphorimaging. The average transgene: endogenous gene ratio for the C line was 0.96 and for the V line 1.08 indicating that the repeat region in the V construct does not cause more T-DNAs to integrate during transformation.

Example 1.3

ACO1 mRNA increased in abundance following wounding and/or treatment of leaves with cycloheximide but accumulation was approximately five times greater after treatment with cycloheximide than after mechanical wounding which we have previously used as a stimulus. Wounding of cycloheximide treated leaves failed to elicit a further increase in ACO1 mRNA amount. We found cycloheximide to be a more reproducible inducer of ACO1 mRNA accumulation than mechanical wounding and so have used it in preference to

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the latter in this study. No further increase in the abundance of ACO1 mRNA was observed when the concentration of cycloheximide was increased from 50 to 250 ug/ml (date not shown).

Example 1.4

5 The 5' end of ACO1 mRNA extracted from plants is heterogeneous but consists of two major species which differ by 2 bases. The 5' untranslated region (both the sense and duplicated antisense sequences) in both of the constructs (C and V) was made approximately 10 base pairs shorter than those of the endogenous gene. This allowed the discrimination of endogenous gene and transgene-derived transcripts by ribonuclease protection assays using a
10 probe transcribed from a genomic ACO1 sequence which extended from the start of the 3'
end of the 5' untranslated region to a Accl site, in the promoter of ACO1, 222 bases
upstream. In RNA from wild type leaves, there were several bands which may arise from distinct RNA species or from breaking of RNA duplexes during digestion. Some of the
bands seem more susceptible to the effects of antisense suppression than others (although the
15 general trend is still suppression).

In leaves from lines V4, V11 and V28 (all <10% ACO activity), there was extensive co-suppression of the endogenous transcripts (relative to wild-type) and the transgene transcripts (relative to those from a control transgene (line C1). V4, V11 and V28 all exhibited greater suppression than the homozygous ACO-antisense line (Hamilton et.al.
20 Nature 346, 284-287(1990)).

The use of the protein synthesis inhibitor cycloheximide as a stimulant of ACO1 RNA accumulation did not obviously alleviate the suppression of this RNA by the sense transgenes in lines V4, V11 or V28.

Although the endogenous genes transcript is unquestionably suppressed, it is possible
25 that the inverted repeat within the 5' end of the V transgene transcript excludes the probe and causes the signal from the transgenic RNA to be underrepresented. This seems unlikely for the following reason. When a probe that was not excluded by the inverted repeat was used to analyse RNA from the V line, the mRNA signal (which, using this probe, is actually the sum of the endogenous and the transgenic RNAs) was still much less than in the wild type. The

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data shows that in the absence of silencing, the abundance of the endogenous and transgenic RNAs are comparable.

Example 1.5

We chose to measure the abundance of unprocessed transcripts in total RNA extracts
5 as a indirect measurement of transcription whilst simultaneously measuring the amount of
processed mRNA. This was achieved using RNA probes transcribed from genomic
sequences spanning introns in ribonuclease protection assays. Since the RNA analysed was
from leaves frozen in liquid nitrogen and then extracted in strongly protein-denaturing
conditions (phenol and detergent) there should have been little opportunity for any resetting
10 of transcription during the process There was a greater abundance of mRNA following
treatment with cycloheximide although the total amount of mRNA in the ACO-AS plants
was reduced. In the ACO-sense line, V11, there was little or no increase in the mRNA
signal. It is likely that this mRNA signal is mainly from the transgene which is transcribed
by the 35S promoter which is not cycloheximide inducible. In contrast, the abundance of the
15 primary transcript in all RNA samples increased following cycloheximide treatment. This
RNA species originates only from the endogenous ACO1 gene since the transgene has no
introns. In all cases the suppressing transgene had little or no effect upon the abundance of
the primary transcript.

Example 1.6

20 Cycloheximide strongly stimulated the accumulation of both the ACO1 primary
transcript and mature mRNA. Quantification of the signal from primary transcripts and
mature ACO1 RNA in wild type leaves before and after treatment with cycloheximide
showed that there was a 6 fold increase in the abundance of unprocessed ACO1 RNA but a
13 fold increase in the amount of processed ACO1 RNA. The abundance of transgenic
25 ACO1 RNA (transcribed from the 35S promoter) in the C line also rose upon treatment with
cycloheximide.

Example 1.7

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digesting RNA was at either 25°C (RNAaseONE) or 37°C RNAaseT1) for 2-4 hours. RNAaseONE was inactivated by the addition of SDS to 0.5% and the protected, double stranded RNAs were precipitated with ethanol and sodium acetate. RNAaseT1 was inactivated and the double stranded RNAs were precipitated by the addition of the 5 inactivation/precipitation solution provided with the RNAase protection kit from Ambion. The protected RNAs were redissolved in 5-10ul of denaturation/loading solution (80% formamide; 10mM EDTA; 0.1% bromophenol blue; 0.1% xylene cyanol; 0.1% SDS), heated to 95°C for 5 minutes and then separated by electrophoresis on a 6-8% 10 polyacrylamide/8M urea/1xTBE gels (the concentration of polyacrylamide depending on upon the sizes of the fragments to be separated). After electrophoresis, the gels were dried and exposed to Kodak x-omat film between two intensifying screens at -70 for the time indicated. The radioactivity was measured by phosphorimaging.

EXAMPLE 2.0

Construction of synthetic heterologous DNA inverted repeat.

15 A synthetic heterologous DNA invert repeat (SEQ ID No 11) was constructed by annealing two sets of synthetic oligos (HIR1 SEQ ID No 12 and HIR2 SEQ ID No 13 and HIR 3 SEQ ID No 14 and HIR 4 SEQ ID No 15) and ligating each set into pSK-(bluescript, Statagene) independently, to create pHIRA and pHIRB respectively. The invert repeat structure was created by digesting both pHIRA/B vectors with XhoI and NcoI and ligating the 42bp 20 fragment from pHIRB into the pHIRA. The invert repeat structure was isolated from the pSK- vector using KpnI and cloned into the KpnI site immediately downstream of the CaMV35S promoter in the plant expression cassette pSIN to create pHIR-SIN.

The tomato ACO1 cDNA (pTOM13) coding sequence was amplified from its original cloning vector pAT153 (promega) using two oligonucleotide primers, 5' 25 CTTTACCAAGAACGTGCACATGGAGAACTTCCC 3' SEQ ID No 6, and 5'GAATTGGGCCCTAACGCACTTGCAATTGG 3' SEQ ID No 7 which prime either side of the TOM13 coding sequence introducing ApaLI and ApaI sites respectively. The PCR product was digested with ApaLI and ApaI and the ends blunted in using Pfu polymerase

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(Stratagene). The blunt PCR fragment was ligated into the SmaI site downstream of the invert repeat structure of pHIR-SIN to create pSIN-HIR-ACO.

The plant expression cassette from pHIR-ACO was isolated using AgeI and ligated into the binary vector pVB6 AgeI site to create pHIR-ACO SEQ ID No 10. The insert was orientated using restriction analysis to ensure that all the ORF that will be active in the plant were unidirectional. pHIR-ACO was transformed into *A.tumafaciens* LBA4404: and this used to transform tomato cotyledons (*Lycopersicum esculentum* var Ailsa Craig). Plants were regenerated from callus.

Example 2.1

10 Identification of Transgenic Plants

DNA was extracted from single leaves and extracted as described previously. Plants containing the HIR-ACO T-DNA insert were identified by PCR using an internal TOM13 sense primer (5' GCTGGACTCAAGTTCAAGCCAAAG 3'SEQ ID No 8) and a NOS 3'UTR (untranslated region) specific antisense primer
15 (5'CCATCTCATATAACGTCATGC3' SEQ ID No 9)

Example 2.2

ACC-oxidase assays

ACC-oxidase activity was measured as the ability of plant tissue to convert exogenous 1-aminocyclopropane-1-1carboxylic acid (ACC) to ethylene. Small leaves were removed from shoots and wounded with a scalpel before being placed into a 2ml sealable vial, and left for 20 30minutes. The vials were then sealed and left for an hour at room temperature , after which the ethylene in the head space was measured by gas chromatography as described my Smith et al., 1986. Ethylene was also measured from wildtype, over-expressing (C12) and antisense down-regulated plant material.

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SEQUENCE LISTING

(1) GENERAL INFORMATION:

5

- (i) APPLICANT:
 - (A) NAME: ZENECA LIMITED
 - (B) STREET: 15 STANHOPE GATE
 - (C) CITY: LONDON
 - (D) STATE: LONDON
 - (E) COUNTRY: UNITED KINGDOM
 - (F) POSTAL CODE (ZIP): W1Y 6LN
 - (G) TELEPHONE: 01344 414521
 - (H) TELEFAX: 01344 481112
 - (I) TELEX: 847556

10

- (ii) TITLE OF INVENTION: GENE SILENCING

15

- (iii) NUMBER OF SEQUENCES: 15

20

- (iv) COMPUTER READABLE FORM:
 - (A) MEDIUM TYPE: Floppy disk
 - (B) COMPUTER: IBM PC compatible
 - (C) OPERATING SYSTEM: PC-DOS/MS-DOS
 - (D) SOFTWARE: PatentIn Release #1.0, Version #1.30 (EPO)

25

- (v) CURRENT APPLICATION DATA:
 - APPLICATION NUMBER:

30

(2) INFORMATION FOR SEQ ID NO: 1:

35

- (i) SEQUENCE CHARACTERISTICS:
 - (A) LENGTH: 3681 base pairs
 - (B) TYPE: nucleic acid
 - (C) STRANDEDNESS: unknown
 - (D) TOPOLOGY: unknown

40

- (ii) MOLECULE TYPE: other nucleic acid
 - (A) DESCRIPTION: /desc = "DNA"

45

- (vi) IMMEDIATE SOURCE:
 - (B) CLONE: SEQ ID NO 1

- (xi) SEQUENCE DESCRIPTION: SEQ ID NO: 1:

AAATTTGATA GATTCA	GTTT	TTATGTTTTT AGTGCTGATT ACAACATTGA AATTCTAAAT	60
TTAGAATT	TAATTTATT	AATGTTAGTG CATTTATACA AATAACATAT TACATCTCAA	120
ATAATATTGA	GT	TTTGTAGA TTTTATTGC CCTGATTCT TATCATAAAT AGGTTTCCT	180
TTTAGGAAAA	GG	TTTTGAAT TGACTATTCT TTTTTGGTA GGAAAAGTT TAGGACTCTA	240
TAAATAGAGG	CATGTT	CCTTTCTT CTAACCTAAC TAGCATTAC AATGTAGTTT TAAGGGCTTT	300
GAGAGTTTG	GTT	AGGGGA GAATTTGTGA ACCTCTCATG TATTCCGAGT GAATTGGTTG	360
AGGTTGTTG	CCT	CCTGTTGATT TTGACTCTG ATGTTATAG TGGATTGCTG ATTTCCTTTG	420
TGGACGTAGG	TCG	TCGATTGACC GAACCACGTT AAATTTTGT CTCTTTGCT ATATTCCTG	480
TTCTTCTTAC	TCG	TCGTGGTCTT TCGAGGTTG CTITGCTAGC TTCCGGCTTT ACACCTGCTT	540

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	ATTTTCGGTC CTAACAAAGTG GSTATCAGAGC CAGATTCAAT AATGGAGTCA GGTGTAGTGG	600
5	TTCGATAATC GATGATTGAA CCAAGTTAGA AAGAGGTGTT CATCTTGACG GGTGTAGTTC	660
	TAGCCGCAAC CTTTTGACA GTAATGAAGA TTTTGATGGA GAAATTGTTT CAGAGAGGTT	720
	CTCTGTGTTG AGACATAAAAT TTTGTAAAGG AGATTATGGA GAGGAGAACG AAGTTGTTGA	780
10	AGATTAAGTA AAGAAGGTGG ACAAAATCTAT TTTGTCAAGAA ATTCAAGGCCA AGGGGGAGAT	840
	TTGTTGGGTT TTATTTGCCG TGATTTTTA CCATAAAATAG GTTTCCCTTT AAGGAAAAGG	900
	TTTGAAATTG ACTATTCTTT TTTGGTAGG AAAAGGTTA GGATTCTATA AATAGAGGCA	960
15	TGTTCCCTCT AACTTAATTA GCATTCACAA TGAGTTTTA AGGGCTTTGA GAGTTTGTT	1020
	TAGAGGGAGA ATTTGTGAAC CTCTCATGTA TTCCGAGTGA ATTGGTTGAG GTTGGTCCC	1080
20	TCTGTATTTT GTACTCTCAT GTTTATAGTG GATTGCTCAT TTCCCTTGAG GACGTAGGTC	1140
	GATTGACCGA ACCACGTTAA ATCTTTGTGT CTTTGGTAT ATTCCTCGTT GTCTTCTTAC	1200
	TCGAGGTTTG CTTTGCTAGC TTCCGCGTTT ACACCTGCTT ATTTGCGGTC	1260
25	CTAACAGAGT TCGATGGGTT GAATCTATAA AAAGAAAAAT ATACTCGTGA TTCACGATTA	1320
	TTTATATCAA AATATAATAA ATATTGAATT TCCTTGCTA TTTCTTATGT TTACGTCTT	1380
30	ATATTCAAA TTATTCCACC AATACTGACA AGCCCTAGGC CATCTCTAGG AAATTCATAC	1440
	AATTTTTTT TTGTTGTTAA CTAGTTAAAT TGGCAGCCTT AAAGATTATT GTAAAATTCA	1500
	AGGCAACTTC CTCAAGTACT ACAACTACAT TGTAACATCC CAGTCAAAGT GTCCTAAAT	1560
35	TTTATAAAAT TTGACACATG AAACAATAGC ACAATAAATT TTAGTACTAT TGCAGCCATG	1620
	GCCCCATAAGC CATCATGTAT TATAGTCAAA ATGGGTCTT TTCCAATTG TCTTGATCCC	1680
40	AAAATCCCTT TGTAGGTAAG ATGGTTAAC AAGGAACATAT GACTCTTAAG GTAGACTTGG	1740
	ACTCATAGAC TTGTCATAAC TCATAAAAGAC TTGGAATATA ATAATTATTC ATTTAAATT	1800
	TAATTCTCTA CTTTAATATC TTCTACTATA AATACCCTTT CAAAGCCTCA TTATTTGTAC	1860
45	ATCAAACATT GATATTCAATC TCTTCAATCT ITTGTATTCA CATATTCTAT TTATTCAATA	1920
	CACTTAGGAA AACACTTTAC CAAGAAATTAGATGGAGAA CTTCCCAATT ATTAACTTGG	1980
50	AAAAGCTCAA TGGAGATGAG AGAGCCAACA CCATGGAAAT GATCAAAGAT GCTTGTGAGA	2040
	ATTGGGGCTT CTTTGAGGTA ATCATAAATT ACATAAACAT ATTAATATGT TTGTTTCAAT	2100
	TTATCAGTCA TACTTTCTC TGTAAAAA TTAATGTCAC TTTCATATT TAATAATTG	2160
55	CATGACATGT TTATAACACA ACAAGATATA GGTTACATTT TGATACATTA TATATPACTT	2220
	CTGTGACAGG ACTCAAAGT CTTTCTTAAT TTCTTGAAATT CAATGATGCA TCAAACAAAG	2280
60	ACACGTTAA TGAAGGGGG AATAGTAATT CTGTTTGCTT ATGTGATCAT TGTASTTGTT	2340
	CAACGATGAA ATTGACATG AATGAAATGGA TACAGTACAGG AATATGAGAA AGGGACATTA	2400
	CAAACGATGCA ATGCAACATA CGTTAAAGGA ACTAGTGTCA AGTAAGGGAC TTGAGGGCTGT	2460

- 24 -

	TCAAGCTGAG GTTACTGATT TAGATTGGGA AAGCACTTTC TTCTTGC GCC ATCTTCC TAC	2520
5	TTCTAAATATC TCTCAAGTAC CCGATCTTGA CGAAGAAC ATAC AGGTACATA AC ATGTGTC CTA	2580
	CATATTGCGT ATATAATAAA TAAACACAAA ATTAAAGTTA TATACGCTGA CAGTATAACT	2640
	AATTATAATG TTGTACCAAA TGATGCAGAG AGGTGATGAG AGATTTGCT AAAAGATTGG	2700
10	AGAAATTGGC TGAGGAGTTA CTTGACTTAC TCTGTGAAAAA TCTTGGACTT GAAAAAGGTT	2760
	ACTTGAAAAA TGCCTTTAT GGATCAAAGA GTCCCAACTT TGTTACTAAA GTTAGCAACT	2820
15	ATCCACCATG TCCTAAAGCCC GATTGATCA AGGGACTCCG CGCTCATACA GACGCAGGAG	2880
	GCATCATACT TCTGTTCCAA GATGACAAAG TGAGTGGC TCAACTCCTC AAAGACGAGC	2940
	AATGGATCGA TGTTCCCTCC ATGCGCCACT CTATTGTGGT TAACCTTGGT GACCAACTTG	3000
20	AGGTACAAGA TTCACTAAAGT GTGTGTGTTT TTATCACTAT AACTTAGAAG TAGTAACTAA	3060
	AAATGGTATT AATGAAATGT TATAAAAACA GGTGATCACT AACGGGAAGT ACAAGAGTGT	3120
	GCTGCACAGA GTAATTGCAC AAACAGACGG GACACGAATG TCATTAGCCT CATTACAA	3180
25	TCCAGGAAGT GATGCAGTAA TATATCCAGC AAAAACTTTG GTGAAAAAG AGGCAGAGGA	3240
	AAGTACACAA GTGTATCCAA AGTTTGTGTT TGATGATTAC ATGAAGTTAT ATGCTGGACT	3300
30	CAAGTTCAA GCCAAAGAGC CAAGATTGA AGCAATGAAG GCAATGGAAA GTGATCCAAT	3360
	TGCAAGTGCT TAGATCCCAA TTCAATTAAA AAAATTGGTG TTTGAAAAAT ATATTAAAT	3420
	ATAGCAATCT ATGTATACAC ATTATTTGCT CTTCTTATGT ATGGTAGAAT AAAGTTAGTA	3480
35	TTAAAAAAAGA TTGTGATTTG CTGCATATGT ATCAAAAAGA GTCTAATAT TTGTATCTAT	3540
	AAATAAGGTG CCTTCTAGTG AAATTATACA AATAATAATT TGGAGTGTAT TGTTCTTCT	3600
40	CATGTAATTAACTTTAAG TATCTTACTT TACAATATAC TGTTCACTTA TTGAACATAT	3660
	TGAGTGATAT ATTGACTCAA T	3681

(2) INFORMATION FOR SEQ ID NO: 2:

45	(i) SEQUENCE CHARACTERISTICS:
	(A) LENGTH: 22 base pairs
	(B) TYPE: nucleic acid
	(C) STRANDEDNESS: unknown
50	(D) TOPOLOGY: unknown
	(ii) MOLECULE TYPE: other nucleic acid
	(A) DESCRIPTION: /desc = "PCR PRIMER"
55	(vii) IMMEDIATE SOURCE:
	(B) CLONE: PCR PRIMER SEQ ID NO 2
60	(xi) SEQUENCE DESCRIPTION: SEQ ID NO: 2:
	CATTCACTTC TTCAATCTTT TG
	(2) INFORMATION FOR SEQ ID NO: 3:

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5 (i) SEQUENCE CHARACTERISTICS:
 (A) LENGTH: 26 base pairs
 (B) TYPE: nucleic acid
 (C) STRANDEDNESS: unknown
 (D) TOPOLOGY: unknown

10 (ii) MOLECULE TYPE: other nucleic acid
 (A) DESCRIPTION: /desc = "PCR PRIMER"

15 (vii) IMMEDIATE SOURCE:
 (B) CLONE: PCR PRIMER SEQ ID NO 3

15 (x1) SEQUENCE DESCRIPTION: SEQ ID NO: 3:

CTTAAATTCTT TGGTAAAGTG TTTTCC

26

20 (2) INFORMATION FOR SEQ ID NO: 4:

25 (i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 33 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: unknown
(D) TOPOLOGY: unknown

30 (iii) MOLECULE TYPE: other nucleic acid
 (A) DESCRIPTION: /desc = "PCR PRIMER"

(vii) IMMEDIATE SOURCE:
 (B) CLONE: PCR PRIMER SEQ ID NO 4

35 (xi) SEQUENCE DESCRIPTION: SEQ ID NO: 4:

ATGGAGAACT TCCCAATTAT TAACTTGGAA AAG

33

40 (2) INFORMATION FOR SEQ ID NO: 5:

45 (i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 30 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: unknown
(D) TOPOLOGY: unknown

50 (ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "PCR PRIMER"
(vii) IMMEDIATE SOURCE:
(B) CLONE: PCR PRIMER SEQ ID NO: 6

(XII) SEQUENCE DESCRIPTION: SEQ ID NO: 6:

CTTACGCGTT GCAATTGGAT CACTTTCGAT

10

60 2 INFORMATION FOR SEQ ID NO: 61

4. SEQUENCE CHARACTERISTICS:
A. LENGTH: 81 base pairs
B. TYPE: Nucleic acids

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- (C) STRANDEDNESS: unknown
(D) TOPOLOGY: unknown
- 5 (ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "PCR PRIMER"
- (vii) IMMEDIATE SOURCE:
(B) CLONE: PCR PRIMER SEQ ID NO 6
- 10 (xi) SEQUENCE DESCRIPTION: SEQ ID NO: 6:
- 15 CTTTACCAAG AAGTGCACAT GGAGAACTTC CC 32
- 15 (2) INFORMATION FOR SEQ ID NO: 7:
- 20 (i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 28 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: unknown
(D) TOPOLOGY: unknown
- 25 (ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "PCR PRIMER"
- (vii) IMMEDIATE SOURCE:
(B) CLONE: PCR PRIMER SEQ ID NO 7
- 30 (xi) SEQUENCE DESCRIPTION: SEQ ID NO: 7:
- 35 GAATTGGGCC CTAAGCACTT GCAATTGG 28
- 35 (2) INFORMATION FOR SEQ ID NO: 8:
- 40 (i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 25 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: unknown
(D) TOPOLOGY: unknown
- 45 (ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "PCR PRIMER"
- (vii) IMMEDIATE SOURCE:
(B) CLONE: PCR PRIMER SEQ ID NO 8
- 50 (xi) SEQUENCE DESCRIPTION: SEQ ID NO: 8:
- 55 GCTGGACTCA AGTTTCAAGG CAAAG 25
- 55 (2) INFORMATION FOR SEQ ID NO: 9:
- 60 (i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 23 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: unknown
(D) TOPOLOGY: unknown
- (ii) MOLECULE TYPE: other nucleic acid

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(A) DESCRIPTION: /desc = "PCR PRIMER"

(vii) IMMEDIATE SOURCE:
 (B) CLONE: PCR PRIMER SEQ ID NO 9

5

(xi) SEQUENCE DESCRIPTION: SEQ ID NO: 9:

10 CCATCTCATA AATAACGTCA TCC 23

(2) INFORMATION FOR SEQ ID NO: 10:

(i) SEQUENCE CHARACTERISTICS:

15 (A) LENGTH: 1949 base pairs
 (B) TYPE: nucleic acid
 (C) STRANDEDNESS: unknown
 (D) TOPOLOGY: unknown

20 (ii) MOLECULE TYPE: other nucleic acid
 (A) DESCRIPTION: /desc = "DNA"

25 (vii) IMMEDIATE SOURCE:
 (B) CLONE: PHIR-ACO SEQ ID NO 10

(xi) SEQUENCE DESCRIPTION: SEQ ID NO: 10:

30 ACCGGTGAAT TCCCATGGAG TCAAAGATTC AAATAGAGGA CCTAACAGAA CTCGCCGTAA 60

AGACTGGCGA ACAGTTCTATA CAGAGTCTCT TACGACTCAA TGACAAGAAG AAAATCTTCG 120

35 TCAACATGGT GGAGCACCGAC ACGCTTGCT ACTCCAAAAA TATCAAAGAT ACAGTCTCAG 180

AAGACCAAAG GGCAATTGAG ACTTTTCAAC AAAGGGTAAT ATCCGGAAAC CTCCTCGGAT 240

40 TCCATTGCC AGCTATCTGT CACTTTATTG TGAAGATAGT GGAAAAGGAG GTGGCTCCTA 300

CAAATGCCAT CATTGCCATA AAGGAAAGGC CATCGTTGAA GATGCCCTCTG CCGACAGTGG 360

TCCCCAAAGAT GGACCCCGAC CCACGAGGAG CATCGTGGAA AAAGAAGACG TTCCAACCAC 420

45 GTCTTCAAAG CAAAGTGGATT GATGTGATAT CTCCACTGAC GAAAGGGATG ACGCACAAATC 480

CCACTATCTT TCGCAAGACC CTTCTCTAT ATAAGGAAGT TCATTTCTATT TGGAGAAGAC 540

50 AGGGTACCGC GGCACGGCCA GGCACGCCGC TGAGGCGGCA GTTTCTCGAG TTTCTGCGGG 600

CTCAGCGGGG TGGGTGGCG TGGCGCCAT GGGCGGGGGG GCTGCAGGAA TTCGATATCA 660

AGCTTATCGA TACCGTGGAC CTGGAGGGGG GGCCTGGTAC CGGATCCCGT GCACATGGAG 720

55 AACTTCCCAA TTATTAACCTT GGAAAAGCTC AATGGAGATG AGAGAGCCAA CACCATGGAA 780

ATGATCAAAG ATGCTTGTGA GAAATTGGGGC TTCTTTGACT CGGTGAACCA TGGAAATTCA 840

CATGAAAGTAA TGGCACACAGT AGAGAAAAATT ACAAAAGGGAC ATTACAAAGAA GTGCATGGAA 900

950 CAGAGGTTTA AGGAAACTAGT GGCAGGTAAG GGAATTGAGG CTGTTCAAGC TGAGGTTACT

GATTTAGATT GGCAGAAGCA GGTCTTCTTC CGCCATCTTC GTCATTCATA TACGTCTCAA 960

1020

- 28 -

	GTACCCGATC TTGACGAAGA ATACAGAGAG GTGATGAGAG ATTTGCTAA AAGATTGGAG	1080
	AAATTGGCTG AGGAGTTACT TGACTTACTC TGTGAAAATC TTGGACTTGA AAAAGGTTAC	1140
5	TTGAAAAATG CCTTTATGG ATCAAAAGGT CCCAACTTTG GTACTAAAGT TAGCAACTAT	1200
	CCACCATGTC CTAAGCCGA TTTGATCAAG GGACTCCGCG CTCATACAGA CGCAGGAGGC	1260
10	ATCATACTTC TGTTCCAAGA TGACAAAGTG AGTGGCCTTC AACTCCTCAA AGACGAGCAA	1320
	TGGATCGATG TTCCTCCCCT GCGCCACTCT ATTGTGGTTA ACCTTGGTGA CCAACTTGAG	1380
	G TGATCACTA ACGGAAAGTA CAAGAGTGTG CTGCACAGAG TAATTGCACA AACAGACGGG	1440
15	ACACGAATGT CATTAGCCTC ATTTTACAAT CCAGGAAGTG ATGCAGTAAT ATATCCAGCA	1500
	AAAACTTGG TTGAAAAAGA GGCAGAGGAA AGTACACAAG TGTATCCAAA GTTTGTGTT	1560
20	GATGATTACA TGAAGTTATA TGCTGGACTC AAGTTCAAG CCAAAGAGCC AAGATTGAA	1620
	GCAATGAAGG CAATGGAAAG TGATCCAATT GCAAGTGCTT AGGGGAGCCT GGGCCCTGC	1680
	AGGTCGTTCA AACATTGGC AATAAAAGTTT CTTAAGATTG AATCCTGTTG CCGGTCTTGC	1740
25	GATGATTATC ATATAATTTC TGTTGAATTA CGAATTGCAT GTAATAATTA ACATGTAATG	1800
	CATGACGTTA TTTATGAGAT GGGTTTTAT GATTAGAGTC CCGCAATTAT ACATTTAATA	1860
	CGCGATAGAA AACAAAATAT AGCGCGCAA CTACCATAAA TTATCGCGCG CGGTGTCATC	1920
30	TATGTTACTA GATCGGAAAG CTTACCGGT	1949

(2) INFORMATION FOR SEQ ID NO: 11:

35	(i) SEQUENCE CHARACTERISTICS:	
	(A) LENGTH: 78 base pairs	
	(B) TYPE: nucleic acid	
	(C) STRANDEDNESS: unknown	
	(D) TOPOLOGY: unknown	
40	(ii) MOLECULE TYPE: other nucleic acid	
	(A) DESCRIPTION: /desc = "PCR PRIMER"	
45	(vii) IMMEDIATE SOURCE:	
	(B) CLONE: SYNTHETIC INVERTED REPEAT SEQ ID NO 11	

50 (xi) SEQUENCE DESCRIPTION: SEQ ID NO: 11:

GC GG CACGGC CAGCCACGCC GCTGAGCCCG CAGTTCTCG AGTTTCTGCG GGCTCAGCGG	60
CGTGGCTGGC CGTGCCGC	73

55 (2) INFORMATION FOR SEQ ID NO: 12:

60	(i) SEQUENCE CHARACTERISTICS:	
	(A) LENGTH: 75 base pairs	
	(B) TYPE: nucleic acid	
	(C) STRANDEDNESS: unknown	
	(D) TOPOLOGY: unknown	
	(iii) MOLECULE TYPE: other nucleic acid	

- 29 -

(A) DESCRIPTION: /desc = "PRIMER"

5 (vii) IMMEDIATE SOURCE:
(B) CLONE: PCR PRIMER SEQ ID NO 12

10 (xi) SEQUENCE DESCRIPTION: SEQ ID NO: 12:

GCGGGTACCG CGGCACGGCC ACCCACGCCG CTGAGCCCGC AGTTTCTCGA GGATGGGTG 60
SCTCCATGGG CGGCG 75

15 (2) INFORMATION FOR SEQ ID NO: 13:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 75 base pairs
(B) TYPE: nucleic acid
20 (C) STRANDEDNESS: unknown
(D) TOPOLOGY: unknown

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "PCR PRIMER"

25 (vii) IMMEDIATE SOURCE:
(B) CLONE: PCR PRIMER SEQ ID NO 13

30 (xi) SEQUENCE DESCRIPTION: SEQ ID NO: 13:

CGCCGCCCAT GGAGCCAACC CATCCTCGAG AAACTGCAGG CTCAGCGGCG TGGCTGGCCG 60
35 TGCGCGCGTA CGCGC 75

(2) INFORMATION FOR SEQ ID NO: 14:

40 (i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 66 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: unknown
45 (D) TOPOLOGY: unknown

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "PCR PRIMER"

50 (vii) IMMEDIATE SOURCE:
(B) CLONE: PCR PRIMER SEQ ID NO 14

55 (xi) SEQUENCE DESCRIPTION: SEQ ID NO: 14:

GGGGCGCGCG CGGAGTTCTG CGGGGCTCAG CGCGGTGGCT GCGCGTGCGC CGCGATGGCGC 60
60 ATCGGG 65

(2) INFORMATION FOR SEQ ID NO: 15:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 66 base pairs

- 30 -

- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: unknown
- (D) TOPOLOGY: unknown

5 (ii) MOLECULE TYPE: other nucleic acid
 (A) DESCRIPTION: /desc = "PCR PRIMER"

10 (vii) IMMEDIATE SOURCE:
 (B) CLONE: PCR PRIMER SEQ ID NO 15

15 (xi) SEQUENCE DESCRIPTION: SEQ ID NO: 15:

CCCTAGGCGC CATGGCGGC ACGGCCAGCC ACGCCGCTGA GCCCCAGAA ACTCGAGCGG	60
CGCCCC	66

20

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Two tandemly linked copies of the 5'UTR (each unit = 79bp; 74.7% (A+T)) were ligated in the inverted orientation between the CaMV 35S promoter and an almost full length ACO1 cDNA (Figure 1). Either unit of this direct repeat has the capacity to form a large cruciform structure with the 5' untranslated region immediately downstream. After 5 *Agrobacterium*-mediated transformation with this construct, 26 out of 28 plants recovered from tissue culture exhibited suppressed ACO activity. A much lower frequency (2/15) of suppression was observed with a control construct which lacked the duplicated 5'UTR but was otherwise the same.

More transgenic plants were obtained with the V construct than with the control 10 construct (as well as exhibiting the high HDGS frequency). It is likely that this is a direct result of reduced ethylene synthesis as a result of ACO gene suppression. Previous results have shown that greatly improved callus regeneration could be achieved after transformation 15 with constructs which contained an ACO-antisense gene.

Of the two plants transformed with the repeat construct that showed no suppression, 15 one, V2, may have had a truncated T-DNA or be an untransformed escape since the transgenic ACO1 sequence could not be amplified. Since the repeat contained DNA sequences already in the gene, it seems unlikely that it is this sequence per se which elicits the effect upon gene silencing. It is much more likely that it is the structure of the repeat 20 DNA (or the transcribed RNA) which is the source of the high frequency of silencing observed. The repeat within the V construct was similar to that with the control construct

Most instances of HDGS are associated with complex transgenic loci that contain repeats or whole or part T-DNAs rather than simple single insertions but it is not known whether this is a primary determinant of suppression or an indirect effect. There are examples where apparently single transgenes are associated with gene silencing but these are 25 in the minority and in at least some of these examples the T-DNAs contain internal repeats. The data presented here suggest that deliberate introduction of small repeats in a transgene can increase the number of transgenic lines in which homologous genes have been suppressed to almost 100%. Sense suppression could be obtained with the control construct but at a much lower frequency. The deliberate introduction of repetitive DNA into a 30 transgene may substitute for a requirement for the insertion of repeated T-DNA units to

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produce silencing. Although the PCR assay used here is not absolutely quantitative, it does suggest that the average transgene dosage is about 2 implying that some of the lines exhibiting suppression have single insertions. In several of our lines, the suppression obtained is profound (Figure 2) which makes this strategy even more attractive to those interested in specifically switching off gene expression. There is one previous report of the deliberate combination of repetitive DNA with a reporter gene effecting increased HDGS: Lohuis et al., Plant Journal, 8, 919-932 (1995) inserted a copy of a randomly isolated repetitive genomic sequence (RPS) upstream of GUS reporter gene and found that this element increased the frequency of variegation of transgene expression. This is an example of cis-inactivation, probably acts at the transcriptional level, and the authors considered it to be distinct from co-suppression/sense-suppression phenomena. Interestingly, the RPS element did not increase the frequency of complete silencing of the transgene. In our example, although the level of suppression is severe in many lines, it is not possible to say whether the degree of suppression is equal in all cells expressing the target gene or if the repeat has simply greatly increased the proportion of cells experiencing suppression.

Example 1.8

Constructs and transformation

The tomato ACO1 cDNA, pTOM13 was released from its original cloning vector, pAT153, (Promega), creating pG31. pG31 was digested with EcoRI and the vector re-ligated to create pTRD. This removed the 5' end of the cDNA which contains approximately 90 base pairs of the 3'untranslated region in the antisense orientation at its 5' end which may have been introduced artefactually during the original cloning of the pTOM13 cDNA . The remaining ACO1 sequence was cut out from pTRD with EcoRI and HindIII and ligated into pT₇T_{3α}18 (BRL) digested by EcoRI and the ends filled in with Klenow enzyme. The 5' untranslated region of the ACO1 transcript (minus approximately 10 bases at the 5' end) was amplified with Taq polymerase from oligo dT-primed cDNA of wounded tomato leaves with the primers 5' CATTCACTCTTCAATCTTTG 3' (SEQ ID No.2) and 5' CTTAATTCTGGTAAAGTGTTTCC 3' (SEQ ID NO.3). This DNA was rendered flush ended with T4 DNA polymerase and ligated with the filled in pTRF to create pM11. This reconstituted the EcoRI site at the 5' end and yielded a translatable ACO1 cDNA

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slightly shorter than the wild type ACO1 mRNA. Sequencing confirmed that the amplified ACO1 sequence was not mutated. pM11 was digested with HindIII and partially with EcoRI and the fragment containing the ACO1 cDNA sequence was filled in with Klenow enzyme, and ligated with SmaI digested pDH51 to create pDHC1. This was digested with XbaI and 5 HindIII, the filled in and the fragment containing the vector, 35S promoter and ACO1 cDNA religated to create pM15. pM17 contains two copies of the 5'UTR of ACO1 tandemly linked and inserted in the antisense orientation upstream of the 5'UTR of ACO1 in pM15. This was made by amplifying the 5'UTR from tomato leaf cDNA (see above) with oligos 5' 10 CATTCACTCTTCAATCTTTG 3' (SEQ ID No.2) and 5'CTTAATTCTTGGTAAAGTGTTTCC 3'(SEQ ID NO.3), polishing the DNA with T4 DNA pol and ligating it into a filled in Acc651 site in pM15 upstream of the 5'UTR of the ACO1 sequence Acc651 (an isoshizomer of KpnI but which gives a 5' overhang). The construction was confirmed by sequencing.

pDHC1 and pM17 were digested with BamHI, BglI and PvuII and the BamHI-PvuII 15 fragments containing the CamV35S-ACO1cDNA sequences were cloned into Bin19 which had been cut by HindIII, filled in and then cut by BamHI. The resulting recombinants were called pBC1 and pBM17 respectively. These plasmids were transformed into *A. tumefaciens* LBA4404: and this used to transform tomato cotyledons (*Lycopersicon esculentum* var Ailsa Craig). Plants were regenerated from callus grown on 50 μ g.ml⁻¹ kanamycin.

20 **Example 1.9**

ACC-oxidase assays

ACC-oxidase activity was measured as the ability of plant tissue to convert exogenous 1-aminocyclopropane-1-carboxylic acid (ACC) to ethylene. Discs were cut from leaf lamina with a sharp cork borer and placed in contact with 0.5ml of 10mM 25 NaH₂PO₄/Na₂HPO₄ (pH7), and 10 mM ACC (Sigma) in 5 ml glass bottles which were then sealed with "Subseal" vaccine caps (Fisons). After 1 hour at room temperature, the ethylene in the head space was measured by gas chromatography as described by Smith et al., 1986. Ethylene was also measured from bottles containing the solution but without leaf

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tissue. These values were subtracted from the values obtained from the bottles containing leaf discs.

Example 1.10

PCR analysis of transgenic plants

5 DNA was extracted from single leaves of wild type plants, plants homozygous for a ACO-antisense gene, and those transformed with the constructs of pBC1 and pBM17. Leaves were frozen in liquid nitrogen, briefly ground in eppendorf tubes with a disposable pipette tip, ground further after the addition of 200µl DNA extraction buffer (1% laurylsarcosine, 0.8% CTAB, 0.8M NaCl, 0.02M EDTA, 0.2M Tris/HCl (pH8)), heated to
10 65°C for 15 minutes, extracted once with phenol/chloroform and the DNA precipitated from the aqueous phase by the addition of 0.6 volumes of isopropanol. The DNA was recovered by centrifugation, the pellets washed in 70% ethanol, dried and redissolved in 200ul, of TE buffer. 1ul of this was used as template for simultaneous PCR amplification of the endogenous ACO1 gene and the transgene using the primers ACO1.1
15 (ATGGAGAACTTCCAATTATTAACCTGGAAAAG SEQ ID NO 4) and the ACO1.2 (CTAAGCACTTGCAATTGGATCACTTCCAT SEQ ID NO 5) for 21 cycles of 30 seconds at 95°C, 30 seconds at 65°C and 1 minute at 72°C. Amplified DNA was separated by electrophoresis in a 0.8% agarose/1xTBE gel and blotted onto HybondN+ in 0.4M NaOH
20 for 6 hours. To detect the amplified ACO sequences, the DNA on the filter was hybridised with random prime labelled ACO1 cDNA. The filter was washed in 0.2xSSPE/1%SDS at 65°C followed by phosphorimaging of the radioactive signal.

Example 1.11

Treatment of leaves with cycloheximide and mechanical wounding

Compound leaves were excised with a sharp scalpel blade and immediately placed
25 under water solution of 50µl.ml⁻¹ cycloheximide (Sigma). Another 3 cm of the stalk was cut from the branch under the solution and the assembly was then left in a laminar airflow for six hours to allow the cycloheximide to enter the leaves.

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To wound leaf tissue, individual leaflets were placed on a hard surface and diced with a sharp scalpel blade approximately 10 times transversely and 5 times longitudinally.

Example 1.12

Northern analysis of ACO mRNA in leaves treated with cycloheximide

RNA was extracted from cycloheximide treated leaves as follows. Tissue was frozen in liquid nitrogen and pulverised either in a coffee grinder (for fruit pericarp, see below) or in a mortar (for leaves). 5ml.gfwt⁻¹ of RNA extraction buffer (Kirby's) was added and the frozen slurry ground further in disposable polypropylene centrifuge tubes with a glass rod. Once thawed, the mixture was extracted twice with phenol/chloroform and the nucleic acids precipitated by the addition of 2.5 volumes of ethanol, 1/10 volume 3M sodium acetate (pH5) and refrigeration at 20°C for 1 hour. After centrifugation at 3000xg for 10 minutes (40 minutes for a fruit extraction), the pellets were redissolved quickly in water (approximately 1ml per gram of tissue) and, an equal vol. of 2x DNA extraction buffer (1.4M NaCl, 2% CTAB, 100mM Tris/HCl (pH8)). Two volumes of precipitation buffer (1%CTAB, 50mM Tris/HCl (pH8)) were added to precipitate the nucleic acids (30 minutes at room temperature suffices) and the precipitate was collected by centrifugation (3000xg/15 minutes). This step was repeated except the pellets were dissolved in 1xDNA extraction buffer. After collection of the second precipitation, the pellets were redissolved in 0.5ml 1M NaCl and immediately reprecipitated with 2.5 volumes of ethanol (-20°C/30 minutes). After centrifugation (10000xg/10 minutes), the pellets were redissolved in 400μl water and extracted twice with phenol/chloroform. The nucleic acids were precipitated and collected as above redissolved in 400μl water. 46ul of 10 x One-Phor-All-Buffer (Pharmacia) was added with 50 units of RNAase-free DNAase (Promega) and the solutions incubated at 37°C for 30 minutes. They were extracted twice with phenol/chloroform, the RNA precipitated and collected as above and finally redissolved in 100-500ul of water. We have found that this relatively extensive purification is necessary if rare transcripts are to be detected by RPA. Also, the RNA readily redissolves which greatly reduces handling time when manipulating this RNA mixed with radioactive probe RNA.

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50 μ g of leaf RNA was mixed with an equal volume of denaturation/loading solution (50% formamide; 25mM sodium phosphate (pH6.5); 10mM EDTA; 6.2% formaldehyde; 200 μ g.ml $^{-1}$ ethidium bromide) and separated by electrophoresis on a 25mM sodium phosphate (pH6.5) /3.7% formaldehyde /1.5% agarose gel in 10mM sodium phosphate (pH6.5)/3.7% formaldehyde with continuous buffer re-circulation. The separated RNA was blotted onto Genescreen (Dupont) hybridisation membrane in 10mM sodium phosphate (pH6.5). The autocrosslink setting on a Stratalink (Stratagene) was used to covalently link the RNA to the filter. The filter was prehybridised and then hybridised with a 32P-random prime labelled ACO1 cDNA probe. The filter was washed in 0.2xSSPE/1%SDS at 65°C and then exposed to Kodak X-omat film between two intensifying screens at -70 for 24 hours. Subsequently the radioactivity in each band was measured by phosphorimaging.

Example 1.13

Ribonuclease protection analysis

RNA was extracted from cycloheximide treated leaves and fruit described above.

15 RNA probes were transcribed with T7 RNA polymerase at 20°C with α -³²P UTP (400Ci. mmol $^{-1}$) as the sole source of UTP. After 1 hour incubation, RNAase-free DNase was used to remove the template and the probe was further purified on 6%polyacrylamide/8M urea/1xTBE gels. The band containing the full length probe was visualised by autoradiography. The gel slice containing this RNA was excised and placed in 20 1ml probe elution buffer (0.5M ammonium acetate; 1mMEDTA; 0.2% SDS) for between 6 and 14 hours at 37°C. Typically, between 20 μ l and 100 μ l of this would be co-precipitated with between 20 or 100 μ g of the RNA to be tested plus two yeast RNA controls. The precipitated RNAs were redissolved in 30 μ l hybridisation solution (80% formamide; 40mM PIPES/NaOH; 0.4M sodium acetate; 1mM EDTA pH should be 6.4) heated to 65°C for 10 minutes and hybridised at 42°C for between 2 to 14 hours. The longer hybridisation times were purely for convenience since we easily detected even rare transcripts after only 2 hours of hybridisation. 300 μ l of RNAase digestion buffer (5mM EDTA; 200mM sodium acetate; 10mM Tris/HCl. Final pH of solution should be 7.5) containing either RNAaseONE (Promega) or RNAase T1 (Ambion) was added to each tube except one containing yeast 25 RNA which received RNAase digestion buffer without any ribonuclease. Incubation of the 30

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CLAIMS

1. A vector for enhancing the inhibition of a selected target gene within an organism, - comprising a gene silencing vector characterised in that the said gene silencing vector includes a inverted repeat of all or part of a polynucleotide region within the vector.
- 5
2. A vector as claimed in claim 1, in which the inverted repeat sequence is a synthetic polynucleotide sequence and its inverted repeat sequence.
- 10
3. A vector as claimed in claim 1, in which the inverted repeat sequence is an inverted repeat of all or part of the said gene silencing vector.
- 15
4. A vector as claimed in claim 3, in which the inverted repeat sequence is an inverted repeat of the 5'-untranslated region of the gene silencing vector.
- 5.
5. A method as claimed in any of claims 1 to 4, in which the inverted repeat is separated from the polynucleotide region by a sequence of nucleotides.
- 6.
6. A method of controlling the expression of a DNA sequence in a target organism, comprising inserting into the genome of said organism an enhanced gene silencing vector as claimed in any of claims 1 to 4.
- 20
- 7.
7. A vector for enhanced gene silencing comprising in sequence a promoter region, a 5'-untranslated region, a transcribable DNA sequence and a 3'-untranslated region containing a polyadenylation signal, characterised in that the said construct includes an inverted repeat of a region of said construct.
- 25
- 8.
8. A vector as claimed in claim 7 in which the inverted repeat is a fragment of the 5'-untranslated region of the said construct.

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9. A vector as claimed in claim 7 or claim 8, in which the inverted repeat is separated from the selected fragment by a sequence of nucleotides acting as a spacer.
10. A vector as claimed in claim 7 or 8 or 9, in which the construct includes a double copy of the inverted repeat.
5
11. A vector as claimed in any of claims 7 to 10, in which the vector two tandem copies of the inverted repeat.
- 10 12. A DNA construct for the inhibition of gene expression comprising in sequence a promoter region, a 5'-untranslated region, a transcribable DNA sequence and a 3'-untranslated region containing a polyadenylation signal, characterised in that the said 5'-untranslated region is contiguous with a pair of tandem inverted repeats of said 5'-untranslated region.
15

C

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FIGURE 1A

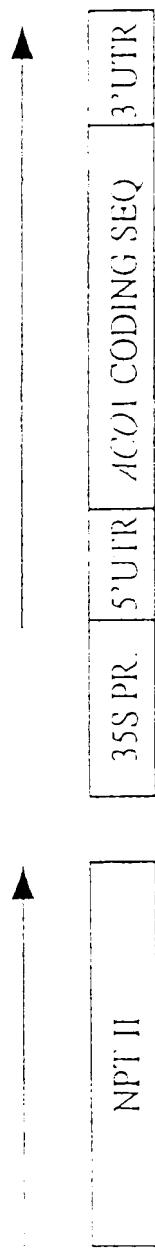
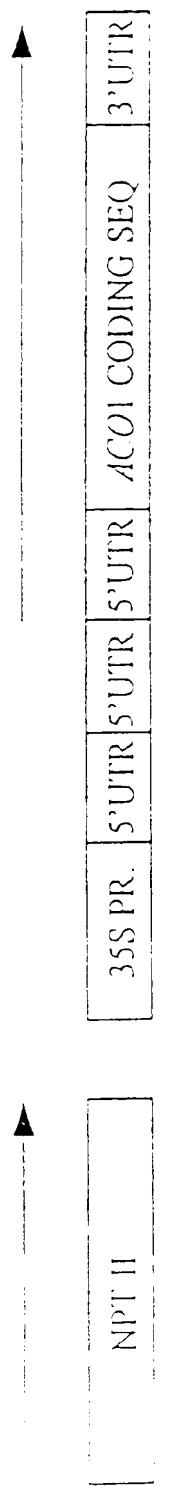


FIGURE 1B

V



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FIGURE 2

Relative ACO activity in plants transformed with
C and V constructs

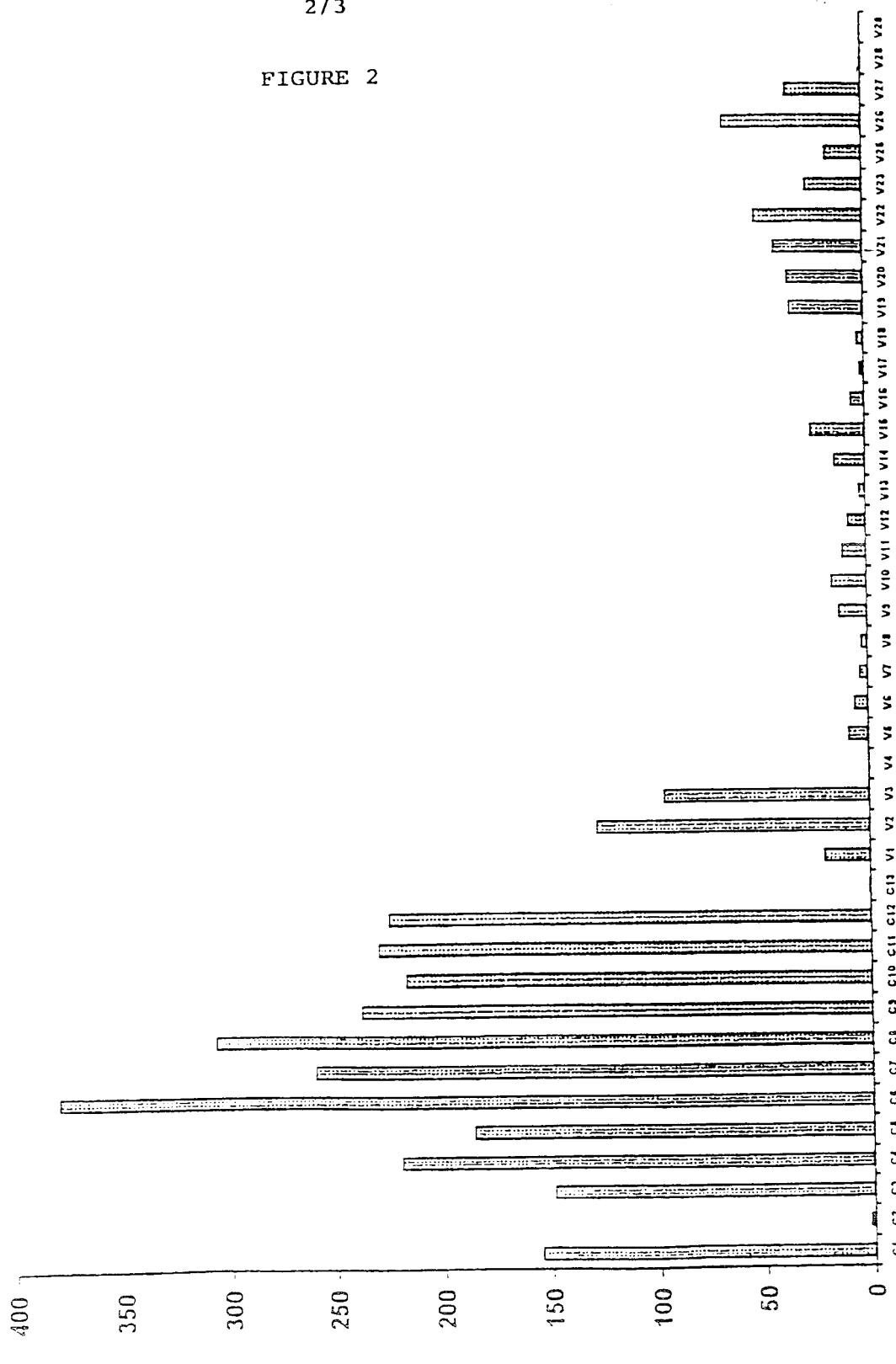
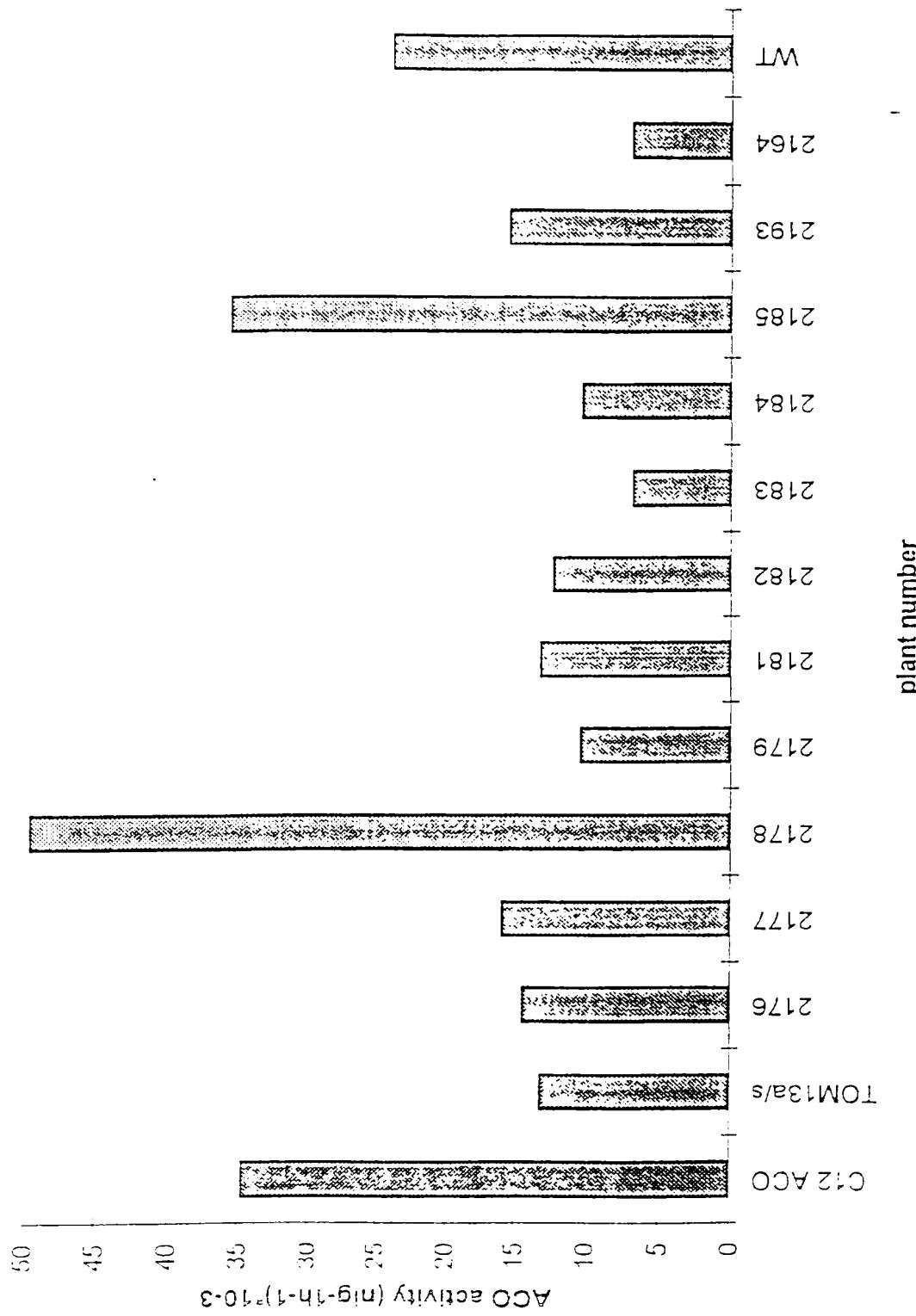


FIGURE 3

ACO activity in plants transformed with pHIR-ACO construct



INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 98/01450

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 C12N15/63 C12N15/82

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 C12N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>DORER D. AND HENIKOFF S.: "Expansions of transgene repeats cause heterochromatin formation and gene silencing in <i>Drosophila</i>" <i>CELL</i>, vol. 77, no. 7, 1 July 1994, pages 993-1002, XP002075449 * see the whole document, esp. discussion, figure 5 *</p> <p>---</p>	1,3,7
A	<p>ASSAAD F. ET AL.: "Epigenetic repeat-induced gene silencing (RIGS) in <i>Arabidopsis</i>" <i>PLANT MOLECULAR BIOLOGY</i>, vol. 22, no. 6, September 1993, pages 1067-1085, XP002075450 * See the whole document, esp. p.1081 l. col. 1.30 - r. col. 1.3 *</p> <p>---</p> <p>-/-</p>	1-12



Further documents are listed in the continuation of box C.



Patent family members are listed in annex

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

National Application No

PCT/GB 98/01450

C (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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A	WO 93 23551 A (SEYMORE GRAHAM BARRON ;TUCKER GREGORY ALAN (GB); GRIERSON DONALD) 25 November 1993 see the whole document ---	1-12
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Information on patent family members

International Application No.

PCT/GB 98/01450

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